Fighting Efficiency as a Determinant of Peace and War*

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Abstract

We develop a two-period rent seeking model with endogenous military investment decisions and shifting combat efficiencies. For peace to obtain it is required that the armies' relative fighting efficiency remains rather constant accross time and that the adequation between wealth and strength is respected. Delay in conflict may occur if the future assaillant's fighting efficiency is sufficiently improved, and if the future victim is wealthy enough. Moreover, we distinguish disputes aiming at modifying the status quo from preventive wars.

Keywords: Delay, Contest, Conflict, Resource Curse

JEL classification: D74, H77

1 Introduction

When property rights over a resource are not exogenously enforced, the agents that have a claim over the 'prize' are the ones who dedicate resources to appropriative activities. Indeed, what has come to be known as the 'economics of conflict' (for early models, see Grossman, 1991; Skaperdas, 1992 and Hirshleifer, 1995; and for a deep review of the literature, Garfinkel and Skaperdas, 2006) asserts that the dispute is likely to be settled either directly, when the players confront their respective armies on the battlefield, or through a negociated settlement in the shadow of power and fighting (Powell, 2000). And while the second solution is

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pareto superior since no resources are wasted in the inefficient fighting activity, this seems not sufficient to avoid countries or factions going to war.

Operating in a two-period framework in which spendings in arms is endogenous, Garfinkel and Skaperdas (2000) show that war can occur in the first period alone. Dynamic incentives to initiate a war are thus different from static ones. If we consider the extreme case in which the loser of a contest is eliminated, we understand that the incentives to wage war in the first period increases as the winning party is able to enjoy the whole pie in the subsequent period without having to arm.

Another strand of the litterature focuses on **situations** in which the likelihood of winning the contest evolves over time. In such a context, Bester and Konrad (2004) show that conflict may be deferred to the second period provided attacking is less efficient than defending. The example depicted in Figure (1) describes the mechanics of this result.

	$k=i$	$k=j$
$U_k(W_1,.) - U_k(P_1,P_2)$	$+1$	-3
$U_k(P_1,W_2) - U_k(P_1,P_2)$	$+3$	-5

$k=i$	$k=j$
$+4$	-6
$+6$	-8

Figure 1:

In Figure (1), the function $U_k(X_1, X_2)$ stands for the life-time utility of player k given that the outcome in time period t is X_t. The outcome in period t can be either peace ($X_t = P_t$), or war ($X_t = W_t$). If war occurs in the first time period, the game ends. We thus compute in each line the incentives of countries to initiate a war in either time period. To begin with, consider the benchmark case where no advantage is conferred to either the attacking or the defending party. Suppose that Figure ($1a$) describes the players' payoffs. We observe that player i would like to initiate a conflict in period 2 while player j would be better off if peace was secured all the way. Since player j anticipates i's intention to attack in period 2, his optimal strategy is to conduct a war in period 1. This benchmark case illustrates the claim of von Clausewitz following which:

> If it is in A's interest not to attack B now but to attack him in 4 weeks, then it is in B's interest not to be attacked in 4 weeks' time, but now. (von Clausewitz, 1976 p.84)

Indeed, in a constant sum game, if a party's expected benefit increases in the future, it is necessary that the opponent's expected benefit shrinks, eventually pushing the latter to a preventive war (Levy, 1987).

Contrast this situation with the case where the defense has a strategic advantage. Let then Figure ($1a$) (Figure ($1b$)) stand for the payoffs of the two players when player i (player j) is the initiator of the conflict. We observe that it is not profitable anymore for player j to wage a preventive war since he would get (-6) by doing so, while his payoff is (-5) if he accepts to be invaded in $t = 2$.

Bester and Konrad (2004) point at the important phenomenon of opposing parties deferring the contest. The downside of their argument is that it relies integrally on the asymetry between attack and defense. This argument seems at first uncontested since as Hirshleifer (2000) reminds us, the $3:1$ ratio is a 'familiar military rule of thumb'; the offender needs as much as three times the strength of the defender to defeat its foe. Hirshleifer, however, also underlines that while this rule of thumb is fairly verified at the time of the military clash, the offender also has strategic advantages to the extent that he can carefully choose the place and time of the confrontation, an argument put forward by Bismark who declared that 'No government, if it regards war as inevitable even if it does not want it, would be so foolish as to leave to the enemy the choice of time and occasion and to wait for the moment which is the most convenient for the enemy' (Levy: 99, 1997). More generally speaking, however, Levy (1984), Biddle (2001), or more recently Gortzak et al. (2005) vividly advise scholars to be extremely cautious when constructing the entire explanatory mechanism of war on the offense-defense balance.

Our objective is to complement the work of Bester and Konrad (2004) by endogenizing the choice of arms levels. By doing so we are able to replicate their main results (existence of delay in contests) without assuming a strategic advantage to defense. The model we develop also helps us to better understand the relationship between utility and resource ownership.

The paper is organized in four sections. We begin by explaining by the use of a simple model howcome a convergence (divergence) of the players' fighting efficiency increases (decreases) the level of military expenditures when working with the Contest Success Functions war technology. In the second section we present the full model and discuss the results. Finally, we provide some concluding remarks in a last section.

2 Contest success functions and fighting efficiency

In this section we study the interlinkings between, on the one hand, the contest success functions, which is the tool we use to model war, and, on the other hand, the agents' warfare efficiency.

Although the contest success functions (CSFs) have traditionally been attributed to Tullock (1967), those functions and their properties remained vastly unexplored until the works Hirshleifer (1989; 1991; 1995), Skaperdas (1992; 1996), Grossman (1995) and Neary (1996). Those functions respect Tullock's initial intuition that the likelihood that one eventually prevails (the burglar or the house owner) is a positive function of the resources invested in the - wasteful - activity (buying explosives or lock picks). Imagine two countries labelled i and j that are in dispute over a good. Country i invests an amount m_i for building up military strength, while the equivalent amount for its foe is given by m_j. The probability that country i eventually obtains the good is then given by:

$$p_{ij} = \frac{(\theta_i m_i)^e}{(\theta_i m_i)^e + (\theta_j m_j)^e} \tag{1}$$

Using Hirshleifer's (2000) vocabulary, θ_i stands for the 'per-unit battle efficiency' of country i's military, while e is the 'decisiveness parameter' that determines the concavity/convexity of the war technology.

Suppose that the two above mentioned countries are going to war over an identically valued prize r, that their fighting technology is given by (1), and that the opportunity cost of purchasing arms equals unity.

The payoff of country i can thus be written as:

$$u_i(m_i, m_j) = \frac{(\theta_i m_i)^e}{(\theta_i m_i)^e + (\theta_j m_j)^e} r - m_i \tag{2}$$

The equilibrium military expenditures are given by:

$$m_i^* = m_j^* = \frac{e\theta_i^e \theta_j^e}{\left(\theta_i^e + \theta_j^e\right)^2} r \tag{3}$$

This eventually gives us the equilibrium probability that each contestant wins the war, which, for player i, can be written as:

$$p_{ij}^* = \frac{\theta_i^e}{\theta_i^e + \theta_j^e} \tag{4}$$

Hence, the payoff of country i is the following:

$$u_i(m_i^*, m_j^*) = \frac{\theta_i^e}{\theta_i^e + \theta_j^e} r - \frac{e\theta_i^e \theta_j^e}{\left(\theta_i^e + \theta_j^e\right)^2} r \tag{5}$$

With respect to the fighting efficiency parameters, it is crucial to notice that a change in the ratio $\alpha = \frac{\theta_i}{\theta_j}$ modifies both the benefits from going to war and the war-related costs at equilibrium. And, whereas the former aspect has been studied by Bester and Konrad (2004), to our knowledge the latter has never been studied. When decreasing α, we immediately see from (4) that the probability that country i wins the war decreases at equlibrium, reducing i's incentives to wage war. The military spendings at equilibrium (second term of equation (5)), however, are also affected by a change in θ_i as Proposition (1) makes clear.

Proposition 1 *In equilibrium, the military costs of war are maximal for $\alpha = 1$, and decrease monotonically as α diverges from this value.*

Proof: We first rewrite (3) as a function of α, so that we have:

$$m_i^* = m_j^* = \frac{e\alpha^e}{\left(\alpha^e + 1\right)^2} r$$

Differentiating with respect to α we obtain :

$$\frac{dm^*}{d\alpha} = \frac{e^2 \alpha^{e-1}(1 - \alpha^e)}{\left(\alpha^e + 1\right)^3} r$$

And this implies that:

$$\frac{dm^*}{d\alpha} \gtreqless 0 \Leftrightarrow \alpha \lesseqgtr 1 \qquad \blacksquare$$

In the next proposition we show that higher values of α $(1/\alpha)$ imply a higher expected utlility for country i (j):

Proposition 2 *When the decisiveness parameter e is not bigger than unity, higher values of α $(1/\alpha)$ imply a higher expected utility for country i (country j). When $e > 1$, the smaller the value of α $(1/\alpha)$ and/or the bigger the value of e, the more likely it is that the expected utility of country i (country j) diminishes with an increase in α.*

Proof: We conduct the analysis for country i alone, the extension to country j being straightforward. The expected utility of country i in Equation (5) can be rewritten as:

$$u_i(m_i^*, m_j^*) = \frac{\alpha^e(\alpha^e + 1 - e)}{(\alpha^e + 1)^2} r$$

Differentiating with respect to α we obtain:

$$\frac{du_i^*}{d\alpha} = \frac{e\alpha^{e-1}[\alpha^e(1+e)+1-e]}{\left(\alpha^e+1\right)^3}r$$

And this implies that:

$$\frac{du_i^*}{d\alpha} \gtreqless 0 \Leftrightarrow \alpha^e \gtreqless \frac{e-1}{e+1} \qquad \blacksquare \tag{6}$$

Following a change in the α parameter, the total utility variation of either country is the result of the interplay of two effects. The first effect is derived from Proposition (1): military spendings increase (decrease) as the relative strength of countries converges (diverges). The second effect captured by Equation (4) establishes the positive relationship between α ($1/\alpha$) and the probability for country i (j) of defeating its foe at equilibrium. From (6), we observe that the payoff of country i may decrease as its relative efficiency is improved for small values of α, combined with high values of e. In that event the increase in military spendings outweighs the larger share of the pie that country i can now obtain.

Having exposed the mechanism that will drive our results, we can move on the full-version model.

3 A Two-Period Model of Territorial Dispute

We now extend the above framework to two periods and give some additional structure to the model. Rather than assuming the countries are *de facto* going to war, we give the decision makers the possibility to strike a peaceful deal, given that they initially partially own the pie. We therefore diverge from the previous framework in that an amount r_i of territory accrues to country i, while country j initially possesses an amount r_j of territory, and $r_i + r_j = r$.

The players' military technology is given by (1) where we set e equal to unity for the sake of simplicity, and θ_k^t ($k = \{i, j\}; t = \{1; 2\}$) is time dependent. Every period t is composed of two stages. In the first stage the decision-makers meet and decide whether they want to conclude a peace agreement or not. These agreements cannot be violated by assumption[1]. In the second stage of the game, the two countries simultaneously decide the amounts to spend in purchasing arms. If war occurs in the first time period, the winner of the contest gains control of the territory over the second period as well. If, however, both countries conclude peace in

[1]This assumption is equivalent to assuming a very high penalty in case the agreement is violated.

$t = 1$, each enjoys its endowment over the first time period, and the same two-stage game is repeated in period 2. Weapons do not accumulate over time (full depreciation) and as a consequence countries do not invest in arms if they have signed a peace agreement. Denoting by W_t and P_t the war and peace outcomes in time period t, country i's life-time payoff can be written as:

$$U_i(P_1, P_2) = 2r_i \tag{7}$$

$$U_i(P_1, W_2) = r_i + \frac{\theta_i^2 m_i^2}{\theta_i^2 m_i^2 + \theta_j^2 m_j^2}(r_i + r_j) - m_i^2 \tag{8}$$

$$U_i(W_1, .) = 2\frac{\theta_i^1 m_i^1}{\theta_i^1 m_i^1 + \theta_j^1 m_j^1}(r_i + r_j) - m_i^1 \tag{9}$$

To solve this game we proceed by backwards induction. If countries go to war in the second time period their optimal military spendings are analogous to the ones derived in equation (3), and we therefore obtain:

$$m_i^2 = m_j^2 = \frac{\theta_i^2 \theta_j^2}{\left(\theta_i^2 + \theta_j^2\right)^2}(r_i + r_j) \tag{10}$$

Players agree on having a peace treaty in $t = 2$ if the peace *outcome* is preferred to the war *outcome* by both players. We denote θ_i^t/θ_j^t by α_t and $r_i/(r_i + r_j)$ by R_i $(= 1 - R_j)$, so that we obtain the following conditions to have peace in $t = 2$:

$$\frac{(\alpha_2)^2}{(\alpha_2 + 1)^2} < R_i \tag{11}$$

$$\frac{1}{(\alpha_2 + 1)^2} < 1 - R_i \tag{12}$$

If war occurs in the first time period, each country chooses the level of equipment that maximizes (9):

$$m_i^1 = m_j^1 = 2\frac{\theta_i^1 \theta_j^1}{\left(\theta_i^1 + \theta_j^1\right)^2}(r_i + r_j) \tag{13}$$

The decision taken in the 1^{st} stage of the 1^{st} time period depends on the expected outcome of period 2. Indeed, if (11) and (12) are satisfied, the two countries sign a peace agreement for the first time period if $U_i(P_1, P_2) > U_i(W, .)$ and $U_j(P_1, P_2) > U_j(W, .)$, using the equilibrium values of m_i^1 and m_j^1 as computed in (13) where necessary. On the other hand, if (11) and (12) are not satisfied, the decision makers anticipate a forthcoming war. Therefore, they compare the utility of going to war in either time period to determine if they propose to sign a peace treaty in the 1^{st} time period or not.

The results obtained can be summarized as follows:

Proposition 3 ***: Outcome of the Game***

i) The countries strike a peace agreement in both time periods if:

$$1 - \frac{1}{(\alpha_t + 1)^2} > R_i > \frac{\alpha_t^2}{(\alpha_t + 1)^2} \text{ }, \forall t \in \{1, 2\} \tag{14}$$

ii) The countries strike a peace in $t = 1$ and go to war in $t = 2$ if:

$$1 + \frac{1}{(\alpha_2 + 1)^2} - 2\frac{1}{(\alpha_1 + 1)^2} > R_i > 2\frac{\alpha_1^2}{(\alpha_1 + 1)^2} - \frac{\alpha_2^2}{(\alpha_2 + 1)^2} \tag{15}$$

$$\text{and} \begin{cases} R_i < \frac{\alpha_2^2}{(\alpha_2+1)^2} \\ \text{or } R_i > \frac{\alpha_2(2+\alpha_2)}{(\alpha_2+1)^2} \end{cases} \tag{16}$$

iii) War occurs in $t = 1$ otherwise.

Proof: Follows from Equations (7), (8), (9), (11), (12), and (13) ■

In order to comment with more precision the conditions securing peace and war in the two time periods, it is interesting to visualize the equilibrium conditions using the simulation technique. We have pictured the outcomes of the game on Figure (2), when the ratio of fighting efficiencies in $t = 1$, α_1, is set to 1/2. On the x-axis, one can read the ratio of fighting efficiencies in $t = 2$, and on the y-axis we have represented the relative endowment of player i, $R_i = \frac{r_i}{r_i + r_j}$. On this Figure, we have thus assumed that j is initially twice as efficient as i in combat. The areas, abc and $a^{'}b^{'}c^{'}$ describe the situations where war is inescapable in $t = 2$ as the adequation between wealth and strength is not respected. In the regions abc ($a^{'}b^{'}c^{'}$ respectively), country i (country j) would attack coutry j (country i) in period 2 if peace was signed in the 1^{st} time period. In the regions $a^{''}b^{''}c^{''}$, On the contrary, peace would prevail throughout the two time periods.

When the parameters are such that country i would attack its foe in the 2^{nd} time period, we distinguish three zones that correspond to three distinct behavior patterns in time period 1. In the a zone, country j initiates a preventive war: country j's decision maker knows that his country's winning odds are too low in the conflict that country i is going to initiate in $t = 2$. Country j therefore precipitates war in the 1^{st} time period. The incentives of country j to initiate a preventive war decrease with R_j because of its increased relative wealth (country j then has less to win and more to lose when going to war), as well as with α_2 (country j's expected payoff from a future war increases). In the b zone, these incentives have disapeared. Indeed, the two countries agree to sign a peace agreement in the 1^{st} time period even though they are both aware of country i's intention to initiate a conflict in the 2^{nd} time period. On the one hand, country i is better off by signing this treaty because of its higher winning odds in the next time period. On the other hand, country j is also willing to postpone war in order to enjoy in the 1^{st} time period the high share of resources it controls (compared to its relative strength). Lastly, in the c zone country i initiates a war in period 1 as this country is poor and does not expects a strong increase in its relative fighting efficiency.

The same reasoning applies to the regions $a^{'}b^{'}c^{'}$ and $a^{''}b^{''}c^{''}$. In the zones $a^{'}$ and $a^{''}$ ($c^{'}$ and $c^{''}$) country j (i) attacks in the 1^{st} time period, while in $b^{'}$ and in $b^{''}$ both countries prefer to strike a peaceful agreement in the first time period.

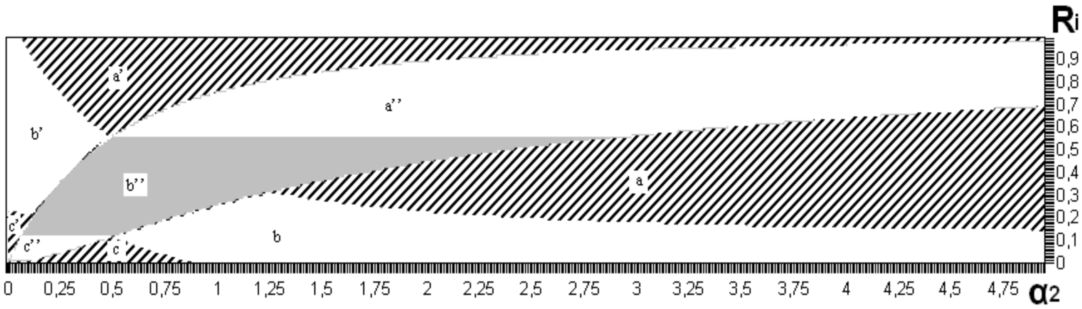

Figure 2: Outcomes for $\alpha_1 = 0.5$

A noticable point to underline is that the range of the share of endowment, R_i, that are compatible with peace in $t = 2$ is the biggest when α_2 equals 1, while this same range of R_i decreases monotonically when α_2 diverges from unity. This observation confirms our previous discussion on the link between fighting expenditures and relative military efficiency (see Proposition (1).

The following proposition establishes a result that will prove helpful in the subsequent discussion:

Proposition 4 *For any configuration of parameter values R_i and α_2 leading to war in $t = 2$, there exists a range of α_1 values such that countries postpone the conflict.*

Proof: See Appendix (A.1)

The Conflict Trap

Equipped with our model we can contribute to the discussion on the link between resources abundance and conflicts. For, indeed, it has been shown that the presence of easily extractable and transportable resources such as gemstones, gold, or oil (Collier and Hoeffler, 2004; Lujala et al., 2005; Collier, 2007) is possitively linked to the occurence of conflicts[2]. The explanation of the 'conflict trap' lies in that when countries are poor, the opportunity cost of joining armed groups is low, thus favouring poverty-inducing conflicts (Ross, 2001, Ross, 2003). A simpler channel, however, simply states the relaxation of the looting rebels' budget constraint, that makes the very existence and development of these movements possible (Collier 2003; Collier and Hoeffler, 2004; Collier, 2007). Since conflicts involve resource-wasteful investments, the welfare consequence of possessing more resources must be negative in a partial equilibrium analysis (i.e. the productive sector is absent from our analysis.) as well. One would then expect the relationship between resource endowment and welfare, if any, to be monotonic: higher amounts of natural resources should imply a higher likelihood of observing conflictual situations, and should thereby decrease the well-being of the increasingly endowed party. By using our framework, we show that while conflict traps do occur in partial equilibrium frameworks, this monotonic relationship needs not necessarily be verified. To illustrate our claim we study how the well-being of a participant varies in our model as we modify his endowment in natural resources. Figure (3) represents the general shape of country i's life-time utility as a function of R_i, when $\alpha_1 = \alpha_2$. The pattern observed on Figure (3) where we vary R_i between zero (country i completely

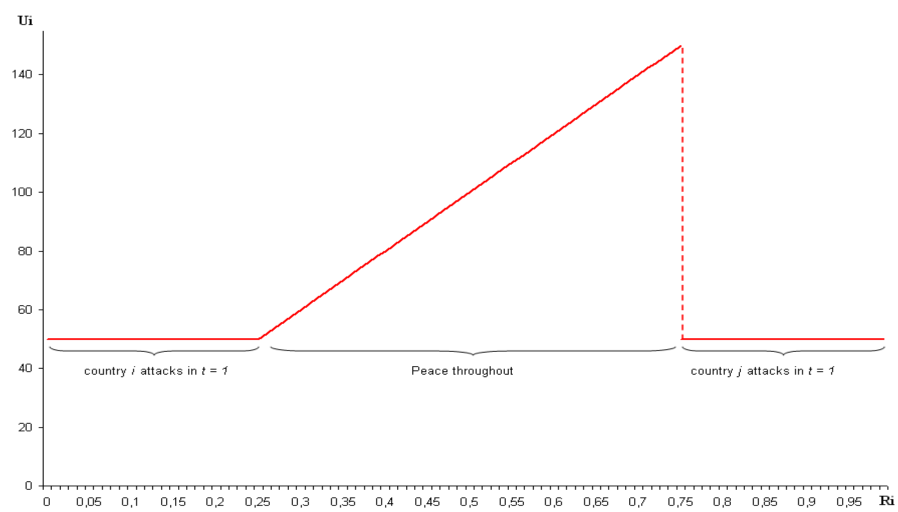

Figure 3: Resource-Wealth relationship for $\alpha_1 = \alpha_2 = 1$

[2]Notice that there is no consensus on the matter since some empirical studies seem to prove the opposite (Smith, 2004).

deprived from resources) and unity (country i possessing the whole pie) seems to confirm the resource curse phenomenon. When the adequation between wealth and strength is violated (extreme values of R_i), war is inescapable. For intermediate wealth distributions, both participants are better off by agreeing not to fight, implying that country i's utility behaves as R_i. The discontinuity appearing on Figure (3) occurs for the value of R_i above which agent j declares war.

When allowing for technological change, more complex patterns may emerge. On Figure (4) we fix $\alpha_1 = 0,5$ and $\alpha_2 = 1,5$ and plot the utility of agent i as a function of his relative wealth.

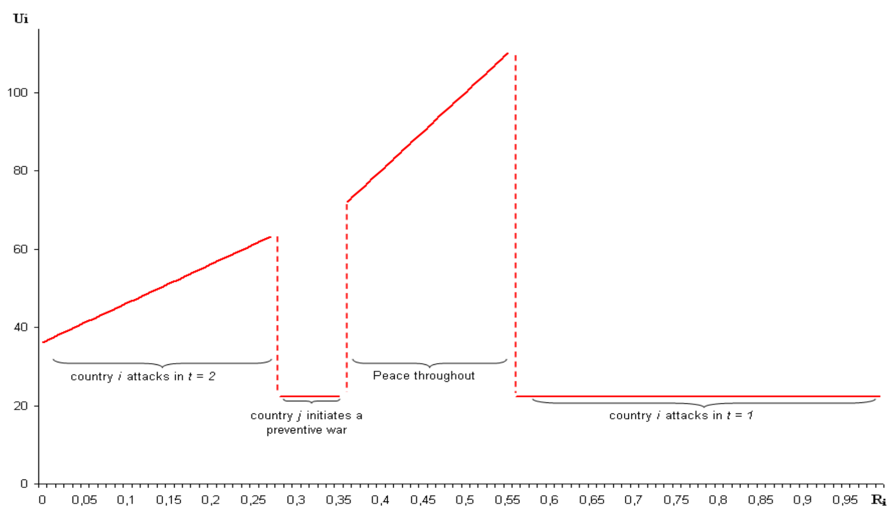

Figure 4: Resource-Wealth relationship for $\alpha_1 = 0.5$ and $\alpha_2 = 1.5$

When country i belongs a small proportion of the overall wealth, the fighting efficiency parameters that we have chosen make it profitable for country i to attack in the 2^{nd} period (zone b on Figure (2)). An increase in country i's relative wealth will therefore push its welfare upwards as it benefits from a bigger share of the resources in the 1^{st} period. When further increasing the relative wealth of country i, there comes a point when its foe decides to conduct a preventive war (zone a on Figure (2)). This explains the first discontinuity of Figure (4). Further increasing R_i drives the game in a peaceful region (zone b'' on Figure (2)). The incentives for country j to attack preventively have vanished because country i is now sufficiently wealthy to sign a peace treaty in the 2^{nd} period. A third discontinuity is observed as the relative resources controlled by country i become sufficiently high. Country j's wealth is so much reduced that going to war in the 1^{st} time period is even more profitable than enjoying the peaceful deal proposed by country i (zones a'' and a'

on Figure (2)).

The Balance of Power Theory and the Power Transition Theory

While economists have only lately been scrutinizing the inefficient allocation of resources to fighting activities, understanding the roots of peace and war has always been a major concern to political scientists. Until recently, the prevalent theory among international relations scholars (Balance of Power Theory, Morgenthau, 1960) has been that war is less likely when the contenders are approximatively equally strengthed, for the outcome of a clash is then the most uncertain. When the countries' power, however, fails to be balanced, the stronger elements will predate the weakest in ordrer to further enhance their power. And although the Balance of Power Theory is extremely more complex and elaborate, the controversy between this theory and the Power Transition Theory (Organski, 1958; Organski and Kugler, 1980) is principally about the necessary conditions to have a peaceful world order. The PT theory views the international order as a pyramid dominated by a single superpower that reigns over all other countries, amongst which one distinguishes regional powers that themselves are located at the top of smaller pyramids. Power Transition theorists claim that the occurence of a conflict initiated by a disatisfied rising challenger is more likely when (*i*) the strength of the contestants is close, and when (*ii*) the rising state's power converges to the one of the dominant state.

From a static viewpoint, our model brings support to the Balance of Power Theory since, as shown in Section 2, the costs of war are the highest when the participants are equally strengthed. Regarding the dynamic version of our model, the relationship between power convergence and the occurrence of war is captured by the following proposition:

Proposition 5 *When the countries' fighting efficiency is expected to totally converge, the power transition theory's predictions are confirmed if the intial relative fighting efficiency* α_1 *is bigger than a threshold* $\bar{\alpha_1}$*, where* $\bar{\alpha_1} \in \left[\sqrt{\frac{2}{1-R_i-\frac{1}{(\alpha_2+1)^2}}}-1;1\right]$*. If* $\alpha_1 < \bar{\alpha_1}$*, we may observe the strongest country leading a preventive war, thus violating the PTT's predictions*

The proof is given in the appendix and to illustrate this proposition, we have represented on Figure (5) an enlarged part of Figure (2) ($\alpha_1 = 0,5$, $R_i \in [0;0,3]$ and $\alpha_2 \in [0,4;1]$). We depict on this Figure two different convergence scenarii. In the first one where $R_i = 0,2$, if no convergence occurs (W) peace is secured over

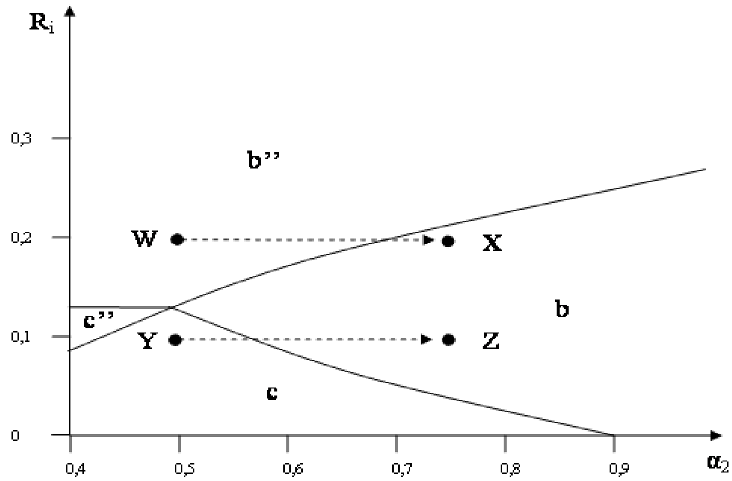

Figure 5: Convergence of power and war ($\alpha_1 = 1/2$)

the two time periods. If, however, the countries' relative military efficiency had shifted from $0,5$ in $t = 1$ to $0,75$ in $t = 2$ (X), the rising state would go to war in $t = 2$, thus corroborating the PTT thesis. In the second scenario where country i is twice richer ($R_i = 0,1$), it decides to attack its foe in $t = 1$ in the absence of convergence (Y). Had the relative military efficiency shifted from $0,5$ in $t = 1$ to $0,75$ in $t = 2$ (Z), the countries would have concluded a peace agreement in $t = 1$, and, again, the rising challenger would have contested the wealth distribution in $t = 2$.

4 Conclusion

In this paper we have complemented the work of Bester and Konrad (2004) by endogenizing the choice of arms levels. We have developed a framework that sheds light on the dynamic incentives of countries to sign peace agreements or to fight in a two period model. For peace to obtain it is required that (i) the armies' relative fighting efficiency remains rather constant accross time and that (ii) the adequation between wealth and strength is respected. In this perfect information framework, we show that two countries may agree to sign a peace agreement in the 1^{st} time period even though they are both aware that one of them has the intention to initiate a conflict in the 2^{nd} time period. On the one hand, the future assaillant is better off by signing this treaty because of its higher winning odds in the next time period. On the other hand, the future victim is also willing to postpone war in order that she enjoys in the 1^{st} time period the high share of resources she controls (compared to its relative strength). Regarding the conflictual outcomes, two reasons may explain the occurrence of war in the first time period. An agent may declare war because of its discontent regarding the status quo. Alternatively, even if the ungoing sharing is acceptable to an agent, the motivation to wage war may reside in a willingness to prevent a future aggression.

It has much been emphasized in the litterature that resource rich countries/regions are more likely to fall in a wealth consuming conflict trap. We are able to replicate the basic intuition following which when an agent's wealth exceeds a threshold, the subsequent agression induces a sharp decrease in his utility. By allowing technological changes over time we understand that the relationship between utility and wealth can be more complex than expected.

A Appendix

A.1 Proof of Proposition (4)

For the first part of the proposition to be true, we need that either of the countries is willing to go to war. There can be at most one country that wants war to occur. Thus, a war in $t = 2$ can either be in country i's interest, in which case we have:

$$\frac{\alpha_2^2}{(1+\alpha_2)^2} > R_i \tag{17}$$

or else country j wants to go to war:

$$R_i > 1 - \frac{1}{(1+\alpha_2)^2} \tag{18}$$

Assume first that equation (17) is true. We then need to show that there always exists a value for α_1 such that we have delay in constests. To have delay in contests, both countries need to prefer peace to war today given the prospects of war tomorrow. These two conditions can be shown to be written as:

$$1 + \frac{1}{(1+\alpha_2)^2} - \frac{2}{(1+\alpha_1)^2} \geq R_i \geq \frac{2\alpha_1^2}{(1+\alpha_1)^2} - \frac{\alpha_2^2}{(1+\alpha_2)^2} \tag{19}$$

Call the two inequalities of (19), inequality (19a) and (19b).

We take the biggest value of α_1 that satisfies inequality (19b). Since $\frac{\alpha_1^2}{(1+\alpha_1)^2}$ is increasing in α_1, this upper bound on α_1, α_1^u, is such that inequality (19b) holds with equality (forget the ϵ difference for it to be true). Then:

$$\begin{aligned}
\frac{2\alpha_1^2}{(1+\alpha_1)^2} &= R_i + \frac{\alpha_2^2}{(1+\alpha_2)^2} \\
\Rightarrow \frac{\alpha_1}{(1+\alpha_1)} &= \left[\frac{1}{2}\left(R_i + \frac{\alpha_2^2}{(1+\alpha_2)^2}\right)\right]^{1/2} \\
\Rightarrow \alpha_1^u &= \frac{\left[\frac{1}{2}\left(R_i + \frac{\alpha_2^2}{(1+\alpha_2)^2}\right)\right]^{1/2}}{1 - \left[\frac{1}{2}\left(R_i + \frac{\alpha_2^2}{(1+\alpha_2)^2}\right)\right]^{1/2}}
\end{aligned}$$

If we are able to show that for $\alpha_1 = \alpha_1^u$ both inequality (19a) and equation (17) are verified, we are done.

With respect to inequality (19a), we can rewrite it by substituting for α_1^u. This yields:

$$\frac{1}{(1+\alpha_2)^2} + 1 - R_i > \frac{2}{\left(\frac{1}{1-\left[\frac{1}{2}\left(R_i+\frac{\alpha_2^2}{(1+\alpha_2)^2}\right)\right]^{1/2}}\right)^2}$$

Which after some manipulations can be written as:

$$\frac{\alpha_2^2}{(1+\alpha_2)^2} - R_i^2 > 2R_i\Big(\frac{\alpha_2}{(1+\alpha_2)} - 1\Big)$$

But, since $\frac{\alpha_2}{(1+\alpha_2)} < 1$, $\frac{\alpha_2}{(1+\alpha_2)} > \frac{\alpha_2^2}{(1+\alpha_2)^2}$, where, by equation (1), this last term is itself bigger to R_i. Hence,

$$\frac{\alpha_2}{(1+\alpha_2)} > R_i$$

Implying that the LHS is positive, while the RHS is negative.

By using the same type of argument we can show that when equation (17) is true there always exists a value for α_1 such that we have delay in constests.

A.2 Proof of the Power Transition Theory

To provide support to the power transition theory we compare a situation where the countries' power converges, $\alpha_2^c \in]\alpha_1; 1]$, with a situation of no convergence, $\alpha_2^{nc} = \alpha_1$. When $\alpha_1 \geq \sqrt{\frac{2}{1-R_i-\frac{1}{(\alpha_2+1)^2}}} - 1$, if we compare the outcomes with α_2^c and with α_2^{nc}, we either have that they are the same, or else we have delay in contests with the rising power (country i) going to war in $t = 2$, thus crediting the PTT.

Looking back at Proposition 3 (Outcome of the game), under α_2^{nc} (i.e. $\alpha_2 = \alpha_1$) we can have (Scenario a) peace in both time periods if Condition (14) is satisfied (point i of the Outcome of the Game), or else the outcome is war in $t = 1$ (point iii) with coutnry i (Scenario b) *or* country j (Scenario c) being the offender. Let us sequentially consider the three scenarii.

Scenario a

To have peace in $t = 1$, it must be that $\big(1 - \frac{1}{(\alpha_1+1)^2}\big) > R_i > \big(\frac{\alpha_1^2}{(\alpha_1+1)^2}\big)$. Given that $\alpha_2^c > \alpha_1$, we have that $\big(1 - \frac{1}{(\alpha_2^c+1)^2}\big) > \big(1 - \frac{1}{(\alpha_1+1)^2}\big)$, implying that the first inequality remains true when replacing α_1 by α_2^c. On the other hand, when setting $\alpha_2 = \alpha_2^c$, we have that $\big(\frac{(\alpha_2^c)^2}{(\alpha_2^c+1)^2}\big) > \big(\frac{\alpha_1^2}{(\alpha_1+1)^2}\big)$, meaning that, either $R_i > \big(\frac{(\alpha_2^c)^2}{(\alpha_2^c+1)^2}\big)$ and therefore peace is ensured in both time periods, or else $\big(\frac{(\alpha_2^c)^2}{(\alpha_2^c+1)^2}\big) \geq R_i$. In the former case, given that $\big(\frac{\alpha^2}{(\alpha+1)^2}\big)$ is monotonically increasing in α, if Condition (14) is satisfied when $\alpha_2 = 1$ (upper bound), then peace always prevails when convergence occurs. If, however, $\big(\frac{(\alpha_2^c)^2}{(\alpha_2^c+1)^2}\big) \geq R_i$ for some α_2^c, the outcome is a delayed war provoked by country i (the challenger) if $\alpha_1 \in [\bar{\alpha_1}; 1]$. This follows from the very computation of $\bar{\alpha_1}$ that is such that $(1 - \frac{2}{(1+\bar{\alpha_1})^2} + \frac{1}{(1+\alpha_2^c)^2}) \geq R_i$.

Scenario b

For the present scenario to be realised, we must have that $\frac{\alpha_1^2}{(\alpha_1+1)^2} > R_i$. We need to show that when $1 \geq \alpha_2^c > \alpha_1$, we can never observe peace in both time periods. This needs no proof since whenever peace is achieved in the first time period, country i has an incentive to attack in the second time period.

Scenario c

For this last scenario to be realised, we must have that $R_i > 1 - \frac{1}{(\alpha_1+1)^2}$. For any $\alpha_2^c \in]\alpha_1; 1]$ we have that the outcome is the same as when $\alpha_2 = \alpha_1$. The reason is simply that since $\frac{d\left(\frac{1}{(\alpha+1)^2}\right)}{d\alpha} < 0$, under α_2^c, $\frac{1}{(\alpha_1+1)^2} > \frac{1}{(\alpha_2^c+1)^2}$, implying that the first inequality of Condition (16) must be violated. And given that Condition (14) is also violated, war occurs in $t = 1$ and the perpetrator is the intially discontented coutry (that is also the initially strongest one).

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